ON GAUGE MEDIATION AND COSMOLOGICAL VACUUM SELECTION

Zygmunt Lalak
Institute of Theoretical Physics, University of Warsaw
ul. Hoża 69, Warsaw, Poland

Gauge mediation of supersymmetry breakdown has many attractive features and can be realized in phenomenologically interesting string-motivated models. We point out that in models with the Polonyi-like field stabilized at a low expectation value by quantum corrections, gravity seems to limit from above the admixture of gravity mediation to the dominant gauge mediation channel. However, we also point out that in a class of such models the low energy metastable supersymmetry breaking vaccum appears to be cosmologically disfavoured. These features should hold also in the case of typical stabilized models with anomalous $U(1)_A$ groups.

1 Introduction

Gauge mediation of supersymmetry breaking [1,2] with the gravitino mass in the GeV mass range appears to be a phenomenologically interesting and theoretically well supported possibility. Heavy gravitino as LSP is an interesting dark matter candidate, allowing for a high reheating temperature needed for leptogenesis. However, to reliably study gauge mediation one needs to take into account the complete theory, with the dynamical supersymmetry breaking sector coupled to messengers and further to the visible sector. A simple and calculable supersymmetry breaking sector is given by the O'Raifeartaigh-type models, see, e.g. [3,4,5,6,7]. The renewed interest in these models is partly motivated by the acceptance of metastable supersymmetry breaking vacua in models with R-symmetry broken spontaneously and/or explicitly by a small parameter. There are two interesting aspects of such scenarios related to gravity. First of all, the gravitational mediation is always present and it is legitimate to ask to what extent one can mix the two channels of mediation. Secondly, one should ask about the cosmological history of the such models. The existence of many competing vacua - spersymmetric and non-supersymmetric ones - poses the question of how natural it is for the complete theory to settle down into the phenomenologically relevant vacuum with broken supersymmetry. We are going to make a few comments on these issues. This summary is based on [8,9].

2 Models of direct gauge mediation

A simple example is a model discussed in [4] with superpotential containing a linear term of a gauge singlet chiral superfield X responsible for supersymmetry breakdown. The messengers Q and q, transmitting the supersymmetry breakdown to the visible sector, transform as $\mathbf{5}$ and $\bar{\mathbf{5}}$ of $SU(5)$ and are coupled to the field X. The superpotential reads $W = FX - \tilde{\lambda}XQq$ and the

form of the Kähler potential,

$$K = \bar{X}X - \frac{(\bar{X}X)^2}{\Lambda^2} + \bar{q}q + \bar{Q}Q\,, \tag{1}$$

takes into account the loop corrections representing the logarithmic divergence in the effective potential coming from the effects of the massive fields in the O'Raifeartaigh model which have been integrated out. The sign of the second term in the Kähler potential is negative here. For $\tilde{\lambda} = 0$ supersymmetry is broken by $F_X \neq 0$ and X is stabilized at 0. Supersymmetry is however restored by turning on the coupling $\tilde{\lambda}$. The supersymmetric global minimum is at $X = 0$ and $Q = q = \sqrt{F/\tilde{\lambda}}$. Coupling the model to gravity changes the vacuum structure. Supersymmetric vacuum is still present as a global minimum (with shifted values of the fields) but in addition a local (metastable) minimum with broken supersymmetry appears, with vanishing vevs for the messenger fields.

A constant c is added to the superpotential to cancel the cosmological constant at the metastable vacuum. Another fact worth mentioning is that, with gravity, after decoupling the messengers ($\tilde{\lambda} = 0$) the supersymmetric vacuum disappears (as in the case without gravity) but the minimum is for X different from zero. In the above discussion, the role of gravity is linked to the negative sign of the second term in the Kähler potential, which follows from the O'Raifeartaigh model. However, more general models of a similar type can give positive sign for that term and X can be stabilized away from the origin, with broken supersymmetry [10], with or without messengers even in the limit $M_P \to \infty$. One can expect that the role of gravity is then more subtle.

3 Graviational vs gauge mediation

We shall now discuss the vacuum structure of a class of globally supersymmetric models under the additional assumption that messengers becoming massless in the limit $X \to 0$ give negligible contribution to the loop-corrected Kähler potential. We expand the loop correction to the Kähler potential in powers of $|X|$:

$$\delta K = -\frac{m^2}{128\pi^2}\left(f_4\Big(\frac{2\lambda|X|}{m}\Big)^4 + \Big(\frac{2\lambda|X|}{m}\Big)^6 + \cdots\right). \tag{2}$$

In (2) we have extracted the overall dependence on the representative mass scale m and coupling strength λ. The scale Λ appearing in eq. (1) is now given (for $f_4 > 0$) by $\Lambda^2 = 8\pi^2 m^2/(\lambda^4 f_4)$ and it can be significantly larger than the scale m, which is the mass scale of the rafertons giving rise to the domninant look correction. In this expansion we denoted by ... terms of higher order in $|X|$ as well as contributions from the messenger sector. We also suppressed the effects of the $|X|^0$ and $|X|^2$. The former amounts to overall rescaling of the potential and the latter is swallowed by the rescaling of X which restores its canonical normalization.

Let us assume the simple superpotential:

$$W = m\phi_1\phi_3 + \frac{R}{2}m\phi_2^2 + \lambda\phi_1\phi_2 X + FX + c\,. \tag{3}$$

A model described by (3) has been extensively studied in the global limit in [10]. Here we couple it to gravity and we again assume that the messenger sector does not affect the position of the local supersymmetry breaking minimum. When $c = FM_P/\sqrt{3}$ the effective potential vanishes in the limit $|X| \to 0$. Only small corrections to this relation are necessary to make the cosmological constant vanish at the supersymmetry breaking local minimum of the potential with $X \neq 0$ and we shall use this approximate relation from now on.

Functions f_4 and f_6, defined in eq. (2), have the following form:

$$f_4 = -\frac{1+2R^2-3R^4+R^2(R^2+3)\ln R^2}{(R^2-1)^3} \tag{4}$$

$$f_6 = \frac{1+27R^2-9R^4-19R^6+6R^2(R^4+5R^2+2)\ln R^2}{3(R^2-1)^5}\,. \tag{5}$$

As shown in [10], the function f_4 is positive for $R < 2.11$ and negative otherwise. The function f_6 is positive for $R > 1/2$, thereby ensuring (in the global limit) the existence of a metastable supersymmetry breaking minimum whenever $f_4 < 0$.

One can envision three main classes of solutions depending on the sign and size of f_4. For $f_4 < 0$ and $f_6 > 0$ we recover the minimum previously discussed in the context of globally supersymmetric model:

$$X^2 = \frac{8|f_4|}{9f_6}\frac{m^2/4}{\lambda^2}\,. \tag{6}$$

For $f_4 > 0$ the position of the supersymmetry breaking minimum is determined by a balance between terms linear and quadratic in X [4]. The solution reads then:

$$X = \frac{1}{2\sqrt{3}}\frac{\Lambda^2}{M_P}\,, \tag{7}$$

where, as before, Λ appearing in (1) is given by$\Lambda = 2\pi m/(\lambda^2 n_\phi^{1/2}|f_4|^{1/2})$. Finally, we may have $f_4 \approx 0$, leading to a dominance of the quartic term over the quadratic one. We find then:

$$X^3 = \frac{16\pi^2}{9\sqrt{3}/2f_6}\frac{m^4}{16\lambda^6 M_P}\,. \tag{8}$$

Note that including the supergravity corrections to the effective potential is crucial for the existence of solutions (7) and (8), for which $\langle X\rangle$ is proportional to negative powers of M_P. All the three solutions (6)-(8) break R-symmetry [11]: in (6) R-symmetry is broken spontaneously, whereas the form of (7) and (8) shows that explicit soft R-symmetry breaking (the constant term c in the superpotential) is transmitted to $\langle X\rangle$ through gravitational interactions. Numerical analysis shows that all the three solutions can be realized in the simple model (3), depending on the value of the mass ratio R.

We note that the local minimum disappears for mass scales of the O'Raifeartaigh sector slightly smaller than $10^{-3}M_P$ This can be understood by noticing that the solution (8), which is a good approximation for sufficiently large m, can be rewritten as:

$$\left(\frac{\lambda X}{m/2}\right)^3 = \frac{32\pi^2}{9\sqrt{3}f_6}\frac{m}{2\lambda^3 M_P^3} \tag{9}$$

If the left-hand side of (8) exceeds unity, our perturbative expansion (2) breaks down and one should not expect the minimum to persist. It also follows from (9) that the maximal scale m for which there exists a local minimum with $X \neq 0$ scales as λ^3, which, upon substitution to (8) shows that the corresponding value of X scales as λ^2. These observations are confirmed by our numerical analysis.

The numerical analysis supports the conclusion that the supergravity corrections provide an upper bound on the values of the mass scale m of the O'Raifeartaigh sector for which the metastable supersymmetry breaking minima exist. In the particular example analyzed here,this bound is $m \lesssim 10^{-3}M_P$, which corresponds to $\Lambda \lesssim 10^{-2}M_P$.

4 Cosmological vacuum selection

To describe the cosmological history of models with direct gauge mediation let us restrict ourselves to the case $f_4 = 1,\ f_6 = 0$. The result is rather generic as confirmed by more general analysis [9]. Let us assume that the hidden sector coupled to messengers is in thermal equilibrium shortly after inflation. This is justified as the interactions of X with messengers and with the observable sector are not suppressed by a large mass scale, like in the case of the purely gravitational mediation. It is rather straightforward to see that at very hight temperatures, $T \ll \tilde{\Lambda}$ the minimum of the effective potential lies very close to the origin in the field space. $Q = q = 0,\ X \approx 0$. As the Universe cools down, at the critical temperature

$$T_{cr} = 2\frac{\mu}{\sqrt{\lambda}}\ , \tag{10}$$

the two minima with nonvanishing expectation values of messengers, $< q >=< Q >\neq 0$, form, which evolve smoothly towards the supersymmetric minima at $T = 0$. The mimimum which corresponds to the supersymmetry breaking minimum at low temperatures forms at the temperature T_X which is typically much lower than T_{cr}:

$$T_X = \mathcal{O}(3)\,\mu\frac{\mu}{\Lambda\lambda} \approx T_{cr}\frac{1}{\sqrt{\lambda}}\frac{\mu}{\Lambda}\ . \tag{11}$$

The possible way out is to arrange for nonadiabatic initial conditions, which give rise to a dispaced intial value for the field X. Analysis of the dynamical evolution indicates, that a suitable set of iniatial conditions leading to enhanced probability of the evolution towards the non-supersymmetric vacuum is $\Lambda^2 < X_{init} < \Lambda$ with $\lambda < 10^{-7},\ 10^{-3} < \Lambda < 10^{-1}$. Interestingly, this points towards the mixed gauge/gravity mediation scenario.

5 Summary

Gauge mediation of supersymmetry breakdown has many attractive features and can be realized in phenomenologically interesting string-motivated models. We point out that in models with the Polonyi-like field stabilized at a low expectation value by quantum corrections, gravity seems to limit from above the admixture of gravity mediation to the dominant gauge mediation channel. However, we also point out that in a class of such models the low energy metastable supersymmetry breaking vaccum appears to be cosmologically disfavoured. Our conclusions are not altered in the models where X is charged under an anomalous $U(1)_A$ group, and coupled to charged modulus, as long as the modulus and the gauge boson of the $U(1)_A$ obtain the Planck scale masses, which is usually the case.

Acknowledgments

This work was partially supported by the EC 6th Framework Programme MRTN-CT-2006-035863, and by TOK Project MTKD-CT-2005-029466. ZL thanks CERN Theory Division for hospitality.

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